EVALUATION OF EXCESSIVE CRACKING IN ASPHALTIC PAVEMENTS

Index

ABSTRACT

In early 1994, several Wisconsin transportation districts identified some asphaltic concrete (AC) pavements constructed between 1990 and 1993 which appeared to have had experienced premature transverse cracking. Possible causes of the premature cracking were identified as: cold weather susceptibility of some of the AC's being used and the unusually cold winter. During the winter of 1993/94 Wisconsin experienced a one-week period of daily high temperatures which did not rise above -15 ºC, and some daily low temperatures as low as -38 ºC. Eleven projects, six good and five bad performing, were selected for evaluation.

These projects were surveyed for transverse cracks in 1994 and in 1997. Results of the 1997 survey showed that all projects had an increase in transverse cracking. Comparison of the study pavements to other similar Wisconsin asphalt pavements of the same age showed more overall cracking for study pavements. Cores were taken from each project in 1995. Dynamic Shear Rheometer, Bending Beam Rheometer and Direct Tension tests were conducted on the extracted binder in these core samples. Results of this testing were compared to the actual crack survey results of the pavements. Direct Tension testing results had the best correlation of the three tests to the transverse cracking observed in 1997.

BACKGROUND

In early 1994, several Wisconsin transportation districts identified some asphaltic concrete (AC) pavements constructed between 1990 and 1993 which, in their judgment, had experienced premature transverse cracking. As a result of these concerns, a committee was formed to determine the causes of this problem. The committee initially identified the possible causes of the premature cracking as: cold weather susceptibility of some of the AC's being used and the unusually cold winter. During the winter of 1993/94 Wisconsin experienced a one-week period of daily high temperatures below -15 ºC, with some daily low temperatures as low as -38 ºC. Each of the eight transportation districts was asked to submit four projects for evaluation (two of which were considered to be performing well and two which were performing poorly). From the projects submitted, six good and five bad were selected for further evaluation.

PERFORMANCE EVALUATION

The initial project selection criteria used were: construction of AC after 1990, virgin mix and on new base. Concerns were expressed that these criteria were too narrow and as a result projects were chosen that did not meet this criteria. This study is concerned with premature cold cracking, which is primarily transverse cracking, and is not concerned with reflective cracking (overlays of PCC or AC pavements), longitudinal, alligator, etc. cracking. Performance evaluation of these pavements was based on crack surveys and Strategic Highway Research Program (SHRP) binder testing. The following projects were selected:

Good Performing AC Pavement Projects:

ID 5290-00-71, District 1

USH 12 - Waunakee Road

STH 19, Dane County

1993 construction, 7.7 km, C1 mix with Quality control (C1Q), 85-100 AC in surface supplied by Amoco, 85-100 AC in lower course supplied by Koch, paved by Payne & Dolan, performing well.

ID 1493-02-71,72, District 3

Wausaukee - Amberg Road

USH 141, Marinette County

June - September 1990 construction, 15.3 km, 112.5 mm single aggregate asphalt over 56.3 mm cold recycled asphalt with emulsion on sandy gravel, 85-100 AC in surface and 120-150 AC in lower course supplied by Koch, paved by Payne & Dolan, performing well.

ID 6991-00-71, District 4

Portage Co. Line - Waupaca Road

STH 54, Waupaca County

1993 construction, 7.3 km, C1Q mix, 85-100 AC in surface and lower course, AC supplied by Amoco, paved by American Asphalt, performing well, little to no transverse cracks.

ID 5162-03-71, District 5

De Soto - Genoa Road

STH 35, Vernon County

1993 construction, 18.9 km, MV mix, 85-100 AC in surface, 85-100 AC in lower course, AC supplied by Koch Oil, paved by Mathy, performing well.

ID 1535-05-71, District 5

Mondovi - Eleva Road

USH 10, Buffalo County

1993 construction, 14.0 km, MV mix, 85-100 AC in surface, AC supplied by Amoco, 120-150 AC in lower course (RAP), AC supplied by Koch Oil, paved by Mathy, performing well.

ID 9092-01-72 / 9093-01-70, District 7

USH 45 - Divide Road

STH 70, Vilas and Forest Counties

1993 construction, 11.8 km, MV mix, 85-100 AC in surface and lower course, AC supplied by Murphy Oil, paved by Northeast Asphalt, performing well.

Poor Performing AC Pavement Projects:

ID 6022-00-73, District 1

North Leeds - Portage Road (STH 16 to Ontario St.)

USH 51, Columbia County

1993 construction, 6.0 km, HV mix, 120-150 AC, paved by Northeast Asphalt, 125 mm virgin asphalt over 400 mm base course or 250 mm base course over existing 150 mm PCCP, very sandy base; coring by District 1 showed cracks to be over joints in concrete.

ID 1490-11-71, District 3

Crivitz - Wausaukee Road

USH 141, Marinette County

June - September 1993 construction, 16.8 km, 37.5 mm virgin MV mix surface, 85-100 AC supplied by Koch, 112.5 mm recycled MV mix lower course, 120-150 AC supplied by Koch, 225 mm crushed gravel over old concrete pavement base, paved by Northeast Asphalt, experiencing premature cracking.

ID 1142-00-73, District 4

Clintonville - Marion Road

USH 45, Waupaca County

1990 construction, 9.7 km, B1 mix with single aggregate on shoulders and median fifth lane, performance is less than desirable, excess transverse cracks showing up in 1994.

ID 1535-05-71, District 5

Mondovi - Eleva Road

USH 10, Trempealeau County

1993 construction, 14.0 km, MV mix, 85-100 AC in surface supplied by Amoco, 120-150 AC in lower course supplied by Koch

Oil, paved by Mathy, experiencing premature cracking.

ID 9131-05-70, District 7

Crandon - Argonne Road

STH 32, Forest County

Fall 1992 / Spring 1993 construction, 9.7 km, C1Q mix, 85-100 AC (surface and lower course), AC supplied by Murphy Oil, paved by Fox Valley Construction, experiencing premature cracking

Crack Count Surveys

The committee established a team to perform the crack surveys and during the summer of 1994, initial crack count surveys were conducted on each of the selected projects. The crack count areas began 805 m from the beginning of the project. At this location 805 m was surveyed for the number and type of crack. The next 2412 m was skipped, then another 805 m was surveyed. This pattern was repeated to the end of the project. The severity of cracks was recorded as "hairline" (crack just visible) and Type I, Type II or Type III as described in the WisDOT "Pavement Surface Distress Survey Manual", where Type I = less than 12.5 mm in width, Type II = greater than 12.5 mm in width, and Type III = band cracking. Since the WisDOT "Pavement Surface Distress Survey Manual" does not distinguish Hairline cracks from Type I cracks, for this report these cracks will be reported as Type I. Follow-up crack counts were conducted in March and April 1997 by Pavement Research and district personnel. Severity types used at this time were limited to Type I, Type II and Type III as described in the WisDOT "Pavement Surface Distress Survey Manual".

Core Samples - SHRP Testing

Four 150 mm cores were taken from the center of the driving lane of each project in the summer of 1994 for binder testing according to SHRP protocol. WisDOT separated the upper and lower layers of the cores and extracted the asphalt cement material from each. To obtain a large enough sample for testing, the extracted asphalt cement material from the upper course cores for each individual project were each combined resulting in 11 upper course samples. This was repeated for the lower course cores resulting in 11 lower course samples. To remove any bias during testing, the samples were numerically coded (see Table 1) and double blind testing was performed. The WisDOT laboratory performed Dynamic Shear Rheometer testing @13 ºC, 16 ºC, 19 ºC, 52 ºC, 58 ºC and 64 ºC. The Asphalt Institute, Lexington, Kentucky, performed Bending Beam Rheometer testing @ -18 ºC, -24 ºC and -30 ºC and Direct Tension testing @ -18 ºC, -24 ºC and -30 ºC. A rating system was devised by the Asphalt Institute to rank the results of the

Bending Beam Rheometer and Direct Tension tests as to their potential cold cracking susceptibility[1]. See Figure 1 for locations of projects and Table 1 for a listing of the cores taken.

Temperature Data

Temperature data, for the area surrounding each project location, was obtained through the UW-Madison, Department Geology and Natural History. This data included daily high/low temperatures for November 1993 through April 1994 and the daily 30-year average high and low temperatures for the months of November through April. The recording station locations used were: Madison, Crivitz, Eau Claire, LaCrosse, Portage, Rhinelander, and Stevens Point (see Figure 1).

PERFORMANCE RESULTS

Study Projects Crack Count Results

Table 2 outlines the results of the crack surveys conducted by the survey teams for both 1994 and 1997. Since the number of crack survey sections varied between projects the average number of cracks per 805 m by type is reported. The initial rating of good or bad performing is also listed.

The results of the 1997 crack survey show an increase in the total number of transverse cracks for every project (Table 2 and Figure 2). Five of the projects had transverse and longitudinal cracks which had been sealed or routed and sealed. To determine if the pavements based on the 1997 crack survey are good or poor performing, the WisDOT **Pavement Management Decision Support - Version 2** (January, 1997) definition of Non-Structural Cracking problems will be used here. Non-Structural Cracking problems are defined as:

> " Cracking of the asphaltic concrete pavement due to temperature changes or aging of the surface. An asphalt pavement has a Non-Structural cracking problem when one or more of the following exits:
>
> - Transverse cracking greater than or equal to minor, and/or
> - Longitudinal Cracking or Longitudinal joint deterioration greater than or equal to minor, and/or
> - Block Cracking greater than or equal to minor."

A minor level problem for transverse cracking is defined as transverse cracking ≤ 12.5 mm wide, 1-5 cracks per station. Based on this, four of the eleven projects (1, 2, 3 and 9) in the study have transverse cracking less than or equal to minor and can still be rated as performing good. Of these four, two had initially been rated as good and two were rated as bad. The remaining seven projects have transverse cracking at the moderate level (cracks ≤ 12.5 mm wide, 6 or more per station or >12.5 mm from 1-10 per station) and can be rated as performing moderately or worse.

Historical Crack Data

Transverse cracking data was obtained from the WisDOT Pavement Information File (PIF) for the years 1990 through 1996 for Wisconsin highways (interstate, US and State Trunk Highways). The criteria used for selection was: 1990 through 1993 construction and asphaltic pavement (no recycled or Stone Matrix Asphalt) paved over milled, new or dense base. Transverse cracking of these highway segments based on extent, severity and age in years is shown in Table 3. It should be pointed out that the total number of highway segments surveyed drops as the age increases because there are fewer 1992 and 1993 pavements that are four or five years old. A gross comparison of these highway segments can be made with the projects in this study. The highway segments in the PIF are 0.1 mi. and the segments in this study were 0.5 mi., so to compare these, cracking per 0.1 mi. was computed. Comparing the four-year old pavements with the 1993 pavements in the study it appears that the study pavements have a higher number of cracks than the average Wisconsin pavement of that age, but not as high of severity level as the 4-year old pavements (Table 3).

SHRP Testing Results

Bending Beam Rheometer (BBR) and Direct Tension (DT): BBR and DT testing, analysis and ranking was performed by the Asphalt Institute[1]. Based on the overall ranking (Direct Tension and creep response) samples 2DU and 2DL had the best rank and sample 11AU had the worst rank. Samples 2DU and 2DL are from USH 51 upper and lower courses. In 1997, USH 51 had an average of 37 cracks per 805 m, only one other project had less transverse cracking (STH 19 with 22 cracks per 805 m). Sample 11AU is from USH 70 upper course. USH 70 had 212 cracks per 805 m in 1997, two other projects had a larger number of transverse cracks per 805 m.

Dynamic Shear Rheometer (DSR): The DSR test results are shown on Table 1, Appendix A. The samples were tested using both the Rolling Thin Film Oven (RTFO) for short term aging and the Pressure Aging Vessel (PAV) for long term (5-10 years) aging properties. All samples passed the 2.20 kPa minimum RTFO specification except sample 3AL (random # 11A) at 64 ºC. The specification maximum for PAV samples is 5000 kPa. Results above this would indicate a potential for fatigue cracking at approximately five years of age. At 13 ºC, all the samples were above 5000 kPa. At 16 ºC, 2CU (random #1B) and 3AL (random #11A) were below the 5000 kPa maximum. At 19 ºC, 10 of the 21 bad samples were below the maximum and 7 of the 21 good samples were below the maximum. A rating system similar to that used by the Asphalt Institute (see Appendix A) was devised to give a relative rating of the DSR results for the PAV samples. For each test temperature (13 ºC, 16 ºC, 19 ºC) the G*(SIN(DELTA)) results were sorted low to high and ranked in increments of 500 kPa. Lower numbers are considered to be better. The individual rankings for each temperature were then summed to give a final rank for each sample (see Table 2, Appendix A). The temperature at which each sample would reach 5000 kPa was also computed and is shown in Table 3, Appendix A. When this temperature is sorted from low to high, it is an fair match to the overall DSR ranks.

Analysis of Data

The 1997 total transverse cracking for each project was plotted against the corresponding DSR, Direct Tension, Creep Response and Overall surface and lower course rankings and regression analyses of the data were performed. Both good and bad pavements were plotted together and separately to determine if there was any difference between the two groups. These results are shown in Figures 3-10. The three data points with an * (Figures 3, 5, and 10) were not included in the calculations for R^2 values because it appeared that these points had been affected by an unexplained experimental or sampling error. Due to the small number of data points available, some general conclusions may be made.

Bending Beam:

Poor correlation was observed between surface rankings and transverse cracking with correlation coefficients (R^2) varying from 0.2686 to 0.7063. The best correlation between the transverse cracking and the creep response rank occurred in the bad initial rating data set indicated by the R^2 value of 0.7063 (Figure 3).

The R^2 values for Bending beam rank for the lower course vs. transverse cracking indicate fairly strong correlation for the good initial rating samples and poor correlation with the other two data sets (Figure 4).

Direct Tension:

Strong correlation was established as indicated by the R^2 of 0.9333 and 0.9467 for the good and the bad initial rating surface course data sets, respectively (Figure 5).

There appears to be no correlation for the lower course samples direct tension and transverse cracking (Figure 6).

Overall (Bending Beam and Direct Tension):

There are no strong correlations between the Overall rankings for surface and lower course data sets and transverse cracking. Some correlation is indicated for the surface bad initial rating and the lower course good initial rating (Figures 7 and 8).

Dynamic Shear Rheometer:

There is some correlation between the surface DSR rankings and transverse cracking (Figure 9). There is a good correlation between the good initial rating data (R^2=0.7788), the bad initial rating data (R^2=0.7317) and the transverse cracking in the lower course samples (Figure 10).

Temperature Data

The temperature data obtained from UW-Madison, Department of Geology and Natural History was plotted for each of the seven recording stations chosen for this study. An example of this is shown in Figure 11 (Rhinelander recording station data). The daily high and low temperatures, along with the 30-year average daily high and low temperatures have been plotted. The week long period from 1/13/94 to 1/20/94 was an extended period of cold weather where daily highs were in many cases below -18 ºC. The daily lows at the seven recording stations during this period ranged between -25 ºC and -38 ºC.

Another period of low temperatures below -18 ºC occurred between 1/30/94 and 2/10/94. The LaCrosse, Portage and Eau Claire recording stations each had one low temperature above -18 ºC in this period (temperatures of -16, -18, and -17 ºC respectively). The Madison recording station had three low temperatures above -18 ºC (-17, -16, -17 ºC).

The coldest part of the winter of 1993/94 appears to be between 1/13/94 and 2/10/94. A comparison of the total number of recorded daily low temperatures below -18 ºC and the total number of recorded 30-year average daily low temperatures below -18 ºC for the period 12/24/93 to 3/01/94 is shown in Table 4. In all cases the 1993/94 totals exceed the 30-year average. The total number of 1993/94 daily highs below -18 ºC also exceeds the 30-year average of zero.

CONCLUSIONS

The regression analyses indicate some correlations between the SHRP test results and actual transverse cracking observed. Based on the regression results, the Direct Tension test (which measures low temperature fracture properties) is the best indicator of transverse cracking for the surface good and surface bad samples.

The creep response (which is a measure of low temperature stiffness) is not a good indicator of transverse cracking when using the full data set for both the surface and lower course samples.

DSR, used to indicate susceptibility to fatigue cracking, showed no correlation to the transverse cracking of the surface samples but a moderate correlation to the lower course samples.

It appears that the amount of cracking of the study projects at 4 years of age is greater than other AC pavements of similar age. But the severity level is less than the pavements of a similar age.

The winter of 1993/94 was colder than the 30-year average account for some of the unexpected cracking noted in AC pavements over that winter.

Currently, WisDOT is using PG 58-28, which by AASHTO MP-1 Performance Graded Asphalt Specifications would have a minimum value of 1% failure strength to be accepted. This should offer reasonable protection against low temperature cracking.

Table 1. AC Sample Coding

Project	District	Highway	Project ID	Good/Bad	Sample	Random #
1	1	STH 19	5290-00-71	G	1BU	5A
					1BL	18A
					1DU	17B
					1DL	20B
2	1	USH 51	6022-00-73	B	2DU	9A
					2DL	16A
					2CU	1B
					2CL	5B
3	3	USH 141	1490-11-71	B	3AU	19A
					3AL	11A
					3CU	10B
					3CL	15B
					4AU	8A

4					4AU	8A
					4AL	15A
					4BU	4B
					4BL	2B
5	4	STH 54	6991-00-71	G	5BU	20A
					5BL	4A
					5CU	7B
					5CL	3B
6	4	USH 45	1142-00-73	B	6AU	2A
					6AL	13A
					6BU	18B
					6BL	14B
7	5	USH 10	1535-05-71	G	7AU	19B
					7AL	8B
					7BU	14A
					7BL	12A

8	5	USH 10	1535-05-71	B	8CU	6A
					8CL	7A
					8DU	9B
					8DL	12B
9	5	USH 35	5162-03-71	G	9A&DU	3A
					9A&DL	21A
10	7	STH 32	9131-05-70	B	10DU	1A
					10DL	10A
					10BU	16B
					10BL	11B
11	7	USH 70	9092-01-72 9093-01-70	G	11AU	17A
					11AL	22A
					11CU	6B
					11CL	13B

A - coded samples sent to Asphalt Institute for testing.
B - coded samples for testing in WisDOT Laboratory.

Table 3. Comparison of Study Pavements and Wisconsin AC Pavements

@ 4 Years Age		Study Pavements	Wis. AC Pavements
	severity	@ 4 years age	@ 4 years age
<1 crack/STA		3.5%	10.4%
1-5 cracks/STA	1	50.0%	49.4%
	2	0.0%	17.1%
	3	0.0%	3.7%
6-10 cracks/STA	1	43.0%	15.2%
	2	0.0%	2.4%
	3	0.0%	0.6%
11-15 cracks/STA	1	3.5%	1.2%
	2	0.0%	0.0%
	3	0%	0.0%

Table 4. Comparison of 1993/94 and 30-year Average Daily Highs and Lows (December 24 through March 01).

Recording Station	Number of Days with High Temperature Below -18 ° C		Number of Days with Low Temperature Below -18 ºC		Coldest Low Temperature Recorded (ºC)	
	1993/94	30-year Ave.	1993/94	30-year Ave.	1993/94	30-year Ave.
Portage	6	0	33	0	-36	-17
Stevens Point	7	0	33	2	-35	-18
Madison	4	0	28	0	-33	-17
Crivitz	7	0	36	19	-38	-20
Eau Claire	8	0	35	19	-36	-20
La Crosse	5	0	31	1	-36	-18
Rhinelander	8	0	39	29	-36	-22

APPENDIX A (not available)

REFERENCES

1. Bahia, H., Hislop, W., Chapelle, C., and Thomas, S. (1996). *Summary Report of Laboratory Testing Data and Analysis for the Research Study "Premature Cracking of Wisconsin*

FIGURES (not available)